DEPARTMENT OF NATIONAL DEFENCE
CANADA

OPERATIONAL RESEARCH DIVISION

DIRECTORATE OF OPERATIONAL RESEARCH (JOINT & LAND)

ORD PROJECT REPORT PR-9718

PERFORMANCE MEASURES FOR THE MATERIEL DISTRIBUTION SYSTEM

by

M. Provencher

DECEMBER 1997

OTTAWA, CANADA

National Defence Défense nationale

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ABSTRACT

Performance measures for the materiel traffic within the Canadian Forces were determined and evaluated. Three areas were addressed: the effectiveness of the distribution of Canadian Forces' materiel, the performance of commercial carriers, and that of the Central Materiel Traffic Terminals (CMTTs). The report shows that the percentages of consignments meeting their Required Delivery Date to be low for high priority consignments however the accuracy of several dates recorded is questioned. Commercial carriers were evaluated according to their cost per weight and distance and their timeliness. Finally the efficiencies of the CMTTs were compared to one another.

RÉSUMÉ

Des mesures de performance sur la circulation du matériel à l'intérieur des Forces canadiennes ont été déterminées et évaluées. Trois domaines ont été adressés: l'efficacité de la distribution du matériel des Forces canadiennes, la performance des transporteurs commerciaux, et celle des centres périphériques de manutention (CPMs). Le rapport montre que les pourcentages d'envois rencontrant la date de livraison demandée sont bas pour des envois de haute priorité cependant la précision de plusieurs dates est en question. Les transporteurs commerciaux ont été évalués suivant leurs coûts par poids et distance et leurs temps de réponse. Finalement les efficacités des CPMs furent comparées entre elles.

EXECUTIVE SUMMARY

In the fall of 1996 a study on productivity measures in transportation was requested by the Directorate of Transport and Movements (DTM). Five key areas of transportation were to be addressed, one of which was operational movements including materiel traffic. This report concerns traffic of Canadian Forces' materiel.

The materiel traffic is monitored through the National Materiel Distribution System (NMDS) from which most of the data was gathered to evaluate the performance measures presented in this report. Three areas of materiel distribution were addressed:

- the efficiency of the distribution of materiel through the percentage of consignments meeting the Required Delivery Date (RDD);

- the performance of the commercial carriers through the cost per weight and distance and the timeliness; and

- the performance of the Central Materiel Traffic Terminals (CMTTs) compared to one another through the materiel handled by each CMTT relative to the number of individuals employed at each CMTT.

The report shows the percentages of consignments meeting the RDD to be fairly low for high priority materiel. However, the accuracy of the dates recorded is questioned, particularly for the reception date and RDD, considering that the days on transportation for several consignments were excessive, e.g., 146 days of transport for one consignment and 201 days for another and there were several cases where the RDD exceeded the reception date by 150 or even 300 days. For materiel priority code 0X the percentage of consignments meeting the RDD is 24 and for code 01 and 02 respectively it is 32 percent and 48 percent.

The commercial carriers performance was compared under four modes of transportation: commercial air, postal, courier and road. They were compared through the cost per weight and distance and the timeliness. The timeliness was measured according to whether the days on transport reflected the requirement set in the transportation priority code which may differ from what was asked of the carrier and as such was not a good time performance measure of the carrier. Additional information should be added to the NMDS to reflect the compliance of the carrier relative to the agreed pick-up and delivery times.

The efficiency of the CMTTs was measured by the ratio of the quantity of materiel handled by the CMTT over the number of individuals in the CMTT. A data envelopment analysis method was used and the CMTTs were rated on a scale from 0 to 1 (1 being best) relative to one another. Two bases showed to be the best performing CMTTs. They were able to do more with the resources they had, either because the quantity of materiel to be handled was relatively greater and/or because the staff was more efficient in doing their work. This evaluation was based on a three month period in 1996 and did not account for the timeliness in the handling of materiel.

TABLE OF CONTENTS

Pages

Abstract/Résumé i

Executive Summary ii

Table of Contents iv

List of Abbreviations v

I. Introduction 1

II. Materiel Traffic 1

III. Effectiveness of Materiel Distribution 5

IV. Carriers Performance 12

V. Efficiency of CMTTs 21

VI. Recommendations 25

VII. Conclusion 26

References 27

Annexes

A- Shortest Distance Between the Origin and the Destination A-1

B- Commercial Carriers Names B-1

C- DEA Model for CMTTs C-1

LIST OF ABBREVIATIONS

CANEX	Canadian Forces Exchange System
CF	Canadian Forces
CFMTS	Canadian Forces Materiel Traffic System
CFSS	Canadian Forces Supply System
CMTT	Central Materiel Traffic Terminal
CPM	Centre périphérique de manutention
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DND	Department of National Defence
DTM	Directorate of Transport and Movements
IOR	Immediate Operational Requirement
MPC	Materiel Priority Code
NMDS	National Materiel Distribution System
PMV	Private Motor Vehicle
RDD	Required Delivery Date
TA	Transportation Agent
TPC	Transportation Priority Code

PERFORMANCE MEASURES FOR THE MATERIEL DISTRIBUTION SYSTEM

I. INTRODUCTION

1. In October 1996, a study on productivity measures in transportation was requested by the Directorate of Transport and Movements (DTM) [1]. Five key areas of transportation were to be addressed: personnel transportation, furniture and effects, postal services, operational movements - materiel traffic, and fleet management. These areas reflect the current composition of DTM. This report concerns operational movements, more specifically the traffic of Canadian Forces' materiel. The report presents different performance measures for the materiel distribution system.

2. The materiel traffic is monitored through the National Materiel Distribution System (NMDS) which is a distributed processing network that has been implemented and installed at 42 sites across Canada and two sites outside Canada, i.e., one in Bosnia, another in Haiti. A review of this system and the information it gathers, allowed us to elaborate performance measures for the distribution of materiel and to evaluate them, when possible.

II. MATERIEL TRAFFIC

3. The basic principle of materiel traffic management within the Canadian Forces (CF) is to effect delivery of the required materiel in serviceable condition, at the place and on the date designated by the consignee, in a safe and cost-effective manner. In addition to the liaison, co-ordination, planning and programming functions, the materiel traffic activity embraces receiving, shipping and customs clearance. It is the general policy of the CF that materiel should be moved by the most practical and efficient means, by either DND or commercial

transport, consistent with urgency and economy. Where adequate and economical DND facilities and equipment are available, they should be utilized to the fullest extent possible [2].

4. Within the CF Supply System (CFSS), materiel requested by a consignee is assigned a Materiel Priority Code (MPC) to reflect the urgency of the requirement for the materiel. These codes are:

a. 0X for immediate operational requirement (IOR);

b. 01 for urgent requirement; the Required Delivery Date (RDD) should be within two to seven days of the demand date;

c. 02 for urgent requirement; the RDD is within four to fifteen days;

d. 03 routine requirement for special projects; the RDD should be within 16 to 60 days of the demand; and

e. 04 routine requirement for stock replenishment; the RDD is always 30 days from the demand date.

5. The movement of Canadian Forces' materiel involves the following sequence of operations: the transportation agent (TA) consolidates consignments into shipments, marshalls the shipments, assigns a Transportation Priority Code (TPC) for each shipment consistent with the materiel priority codes of the consignments, selects and arranges transportation for the safe loading and dispatch of shipments; a commercial carrier or CF carrier transports the shipments to the specific destinations and a destination TA receives and inspects incoming shipments for loss or damage.

6. Within the CF Materiel Traffic System (CFMTS), transportation priority codes are assigned to shipments to reflect the urgency of the requirement for the materiel and the nature of the materiel. The TPC is a two character, numeric-alpha code. The numeric character denotes the basic priority of the shipment based upon the number of days remaining to RDD (time to RDD). The alpha character denotes the handling precedence as well as the source/type of materiel in the shipment (Table I). The "time to RDD" is measured from the date the

TABLE I
ALPHA CHARACTERS

Description of Materiel	Alpha Character
CFSS Code 0X (IOR)	A
Other DND Materiel (IOR)	B
Non-DND Materiel (IOR)	C
CFSS Code 01	D
Mail (Letter)	E
CFSS Code 02	F
Unaccompanied Baggage	G
Bulk Mail (Printed Matter and Parcel Mail)	H
CFSS Code 03	J
CFSS Code 04	K
Other DND Materiel	L
Amenities	M
Non-DND Materiel	N
Private Motor Vehicle (PMV)	P
Canadian Forces Exchange System (CANEX)	R
Not allocated at this time	S-Z

materiel is presented to the shipper, referred to as "date to movements". The time schedule of events is represented in Figure 1. Note that occasionnally the RDD will be passed before the shipment date or even the date to movements. The appropriate "time to RDD" character is determined by the difference between the RDD and the "date to movements" according to the time frames indicated in Table II.

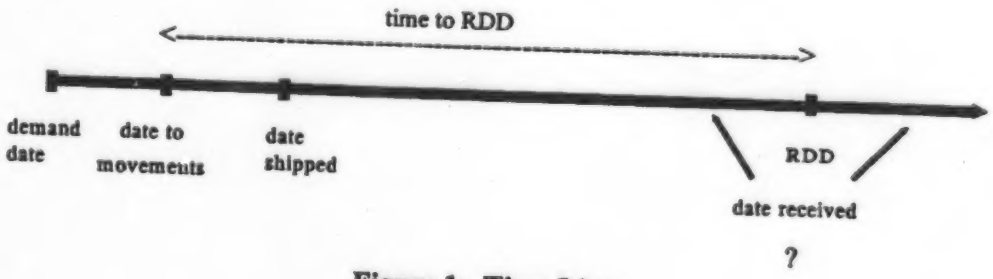


Figure 1: Time Line

TABLE II
NUMERIC CHARACTER

Time to RDD	Numeric
0-0 days	1 (IOR only)
0-3 days	2
4-7 days	3
8-15 days	4
16-22 days	5
23-34 days	6
35 days	7

This way, all TAs may quickly determine the handling and shipping precedence of various shipments, for example, TPC 2G has precedence over 3G and 5J has precedence over 5K. Essentially the priority is decreasing with increasing numeric code and increasing alpha code.

7. Canadian Forces materiel can be transported by DND vehicles, be it base mobile support equipment, service airflights, or inter-base bus service, or by commercial means, i.e., road, courier, rail, post, etc. The delivery date required or due date is the overriding consideration in selecting the mode of transportation. The lowest cost mode that satisfies the due date should normally be used.

8. In looking at the overall materiel distribution system using essentially the NMDS as the source of information, three areas were addressed: the effectiveness of the distribution of materiel, the performance of the carriers, and that of the Central Materiel Traffic Terminals (CMTTs), i.e., the second line materiel traffic sections. The latter was specifically addressed to represent some of the utilisation of personnel in the materiel traffic.

9. The following sections will present the performance measures adopted and evaluated, along with any other informative elements when available.

III. EFFECTIVENESS OF MATERIEL DISTRIBUTION

10. A data sample covering all consignments transported from July 1 1996 to February 3 1997 (more than six months of data) was retrieved from the National Materiel Distribution System. Having discarded records where the destination TA, date shipped, date received or transportation mode were missing i.e. 617 records, a total of 101 260 records (consignments) were left to analyse. The objective of the distribution system is to provide the right item at the right place at the right time. The determining factor being timeliness: materiel should be delivered to the consignee by the Required Delivery Date (RDD). A logical measure of performance here is:

$$\frac{\text{number of consignments delivered within the RDD}}{\text{total number of consignments}} \times 100$$

that is, the percentage of consignments meeting the RDD.

11. This measure was evaluated for the sample by materiel priority code and is presented in Table III along with that percentage when preshipment RDD violations are removed. Confidence intervals around the percentages were too narrow to represent. A preshipment violation occurs when a consignment's due date has already passed when shipped by the originating TA. A histogram of the number of consignments by MPC is provided in Figure 2.

TABLE III

CONSIGNMENTS MEETING RDD

MPC	Percentage of consignments meeting RDD	Percentage of consignments meeting RDD when preshipment violations are excluded
0X	24	28
01	32	45
02	48	59
03	72	80
04	69	74

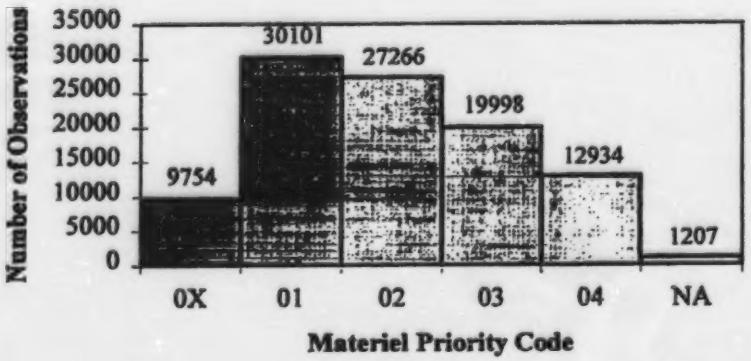
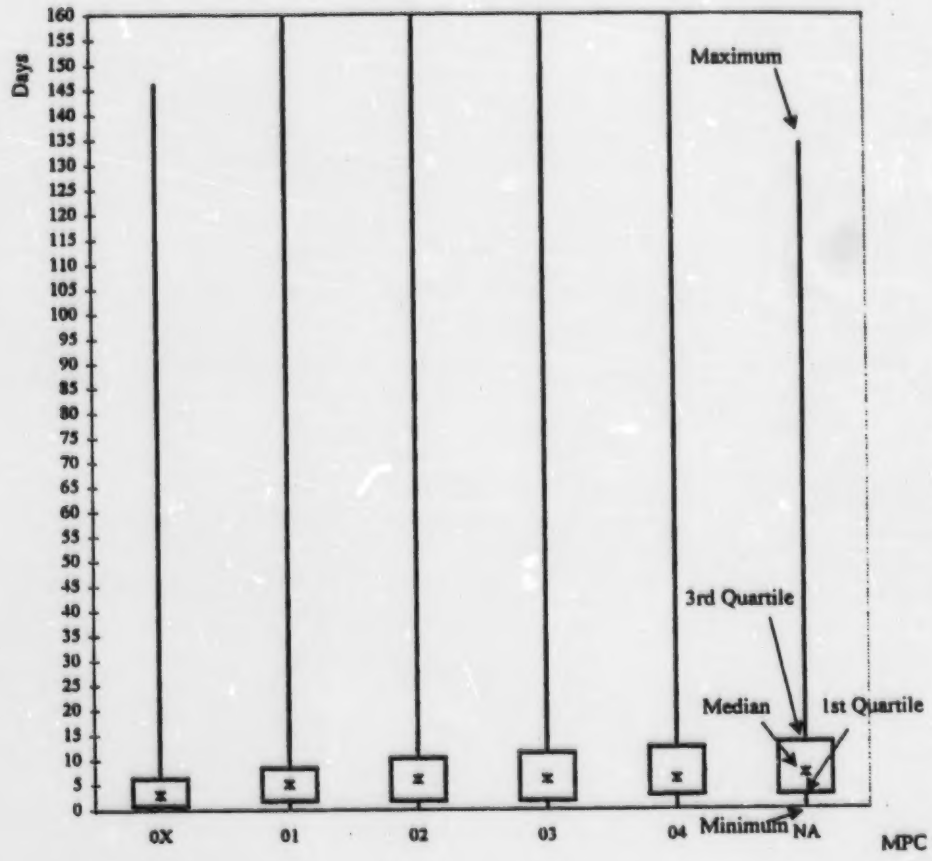


Figure 2: Distribution of Consignments by Materiel Priority Code

Note that all records which did not have an MPC were labelled NA (Not Applicable). Materiel that has an immediate operational requirement represents 10% of all the materiel transported. It has the highest priority, yet an 0X consignment will meet its RDD only 24% of the time on average. Even if we eliminate those cases where a consignment does not meet the RDD before it is shipped, the percentage raises to only 28%. Materiel with code 01 for urgent requirement represents 30% of all materiel and a consignment with that priority code will meet its due date 32% of the time. Only for routine requirement codes 03 and 04 is the RDD met more than 50% of the time.

12. It is important to note that while the date that a consignment is shipped is accurate according to the users of the system, the date that it is received may not be. Reception dates can be entered into the NMDS long after the materiel has arrived because the main task having been accomplished the update of the record in the NMDS is not perceived as important, in which case the percentage of consignments meeting RDD would be



Maximum	146	168	193	168	201	134
3rd Quartile	6	8	10	11	12	13
Median	3	5	6	6	6	7
1st Quartile	1	2	2	2	3	3
Minimum	0	0	0	0	0	0

Figure 3: Boxplots of transportation days of consignments per MPC

underestimated. This may be reflected by the distribution of the number of days of transportation for a consignment by materiel priority code as illustrated in Figure 3. The number of days on transportation for a consignment is calculated as the difference between the date it is received and the date it is shipped. The median number of transportation days per priority coded 0X materiel is 3, 01 materiel is 5, and 02, 03 and 04 materiel is 6. The median is a measure of centrality of the distribution. A median of 3 means that 50% of the observations are below or equal to this value (and 50% are above). Figure 3 illustrates the distribution through boxplots. Boxplots provide a simple graphical means of comparing distributions in terms of location and spread. The minimum, 1st quartile (or 25th percentile), the median, 3rd quartile (75th percentile) and maximum are provided. The box represents the spread of 50% of the data around the median. What is striking in Figure 3 is the spread of the distributions. While more than 75% of the data for each boxplot lies within 15 days for all materiel codes, some values extend up to 201 days.

13. Consignments are sent through various modes of transportation, some commercial, some departmental, the most prevalent one being road, as illustrated in Figure 4. Commercial road transport accounts for 57% of the transport of consignments. The definitions for each mode of transportation taken from [3], are provided in Table IV. Only 21% of all transport of consignments is done through the departmental resources which emphasizes the need to choose commercial carriers judiciously.

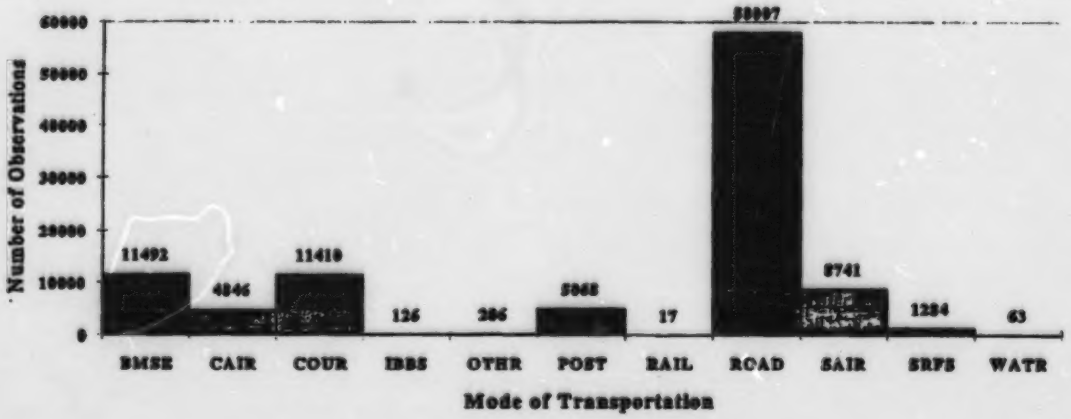


Figure 4: Distribution of Consignments by Transportation Mode

TABLE IV

MODES OF TRANSPORTATION

**indicates a commercial type of transport*

Mode		Description
BMSE		Base Mobile Support Equipment
CAIR	*	Commercial Air
COUR	*	Courier
IBBS		InterBase Bus Service
OTHR		Other/Combination of different modes
POST	*	Postal
RAIL	*	Rail
ROAD	*	Road
SAIR		CF Aircraft
SRFS		Scheduled Road Freight Service
WATR	*	Water

14. Boxplots of the number of days left to the RDD (RDD-Date Received) per transportation mode are presented in Figure 5. The variation around zero, that is the point when the reception date equals the due date is large in both directions: negative (being late) or, positive (being early). The discrepancies between the due date and the reception date can exceed 300 days either way. This would imply that not only can the date received be inaccurate but the RDD can be set close to a year from the date of the demand. Obviously dates should be validated at the time of input by the user.

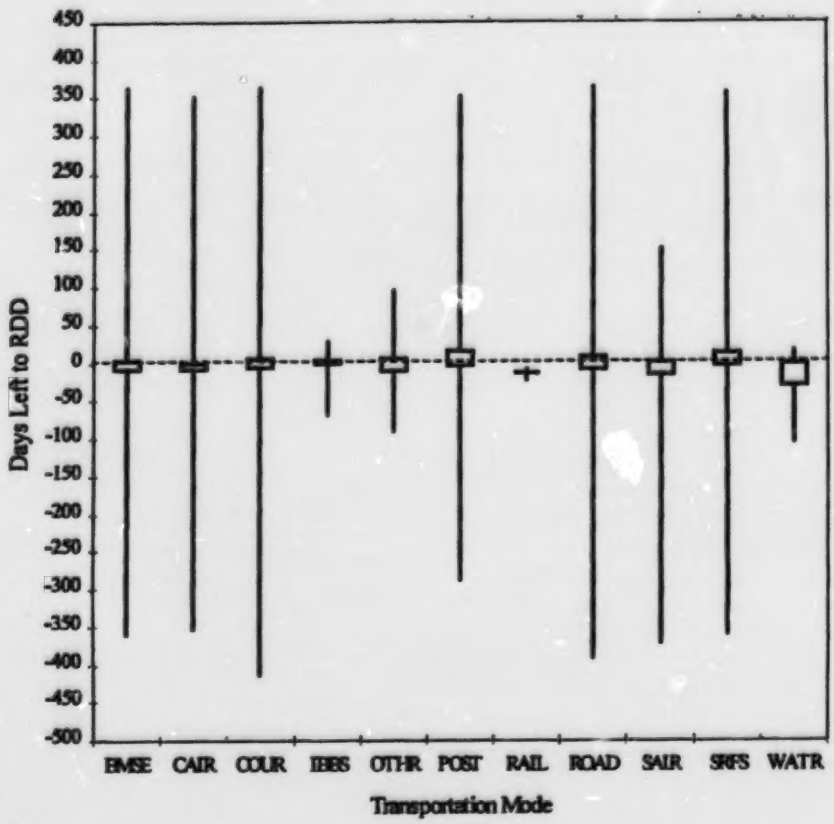
15. As a matter of interest a regression of the RDD-Date Received was done over the RDD-Date Shipped, [4]. A model whose dependent variable is the time left to the due date from the reception could be used to represent the relationship between what we got from what we had, i.e., the time left to the due date from the shipment date. The regression obtained can be expressed as follows:

$$Y = -9 + X + \varepsilon$$

where Y = RDD-Date Received

X = RDD-Date Shipped, and

ε is a normally distributed random variable whose mean is 0 and standard deviation is 15 days.



	EMSE	CAIR	COUR	IBBS	OTHR	POST	RAIL	ROAD	SAIR	SFFS	WATR
Maximum	363	351	362	28	95	351	-9	363	151	357	15
3rd Quartile	4	0	6	4	7	16	-13	8	2	14	-2
Median	-2	-3	0	1	-1.5	6	-13	0	-7	5	-15
1st Quartile	-8	-9	-5	-2	-10	-3	-13	-7	-16	-4	-29
Minimum	-361	-352	-412	-68	-89	-287	-22	-391	-372	-359	-105

Figure 5: Boxplots of Days Left to RDD per Transportation Mode

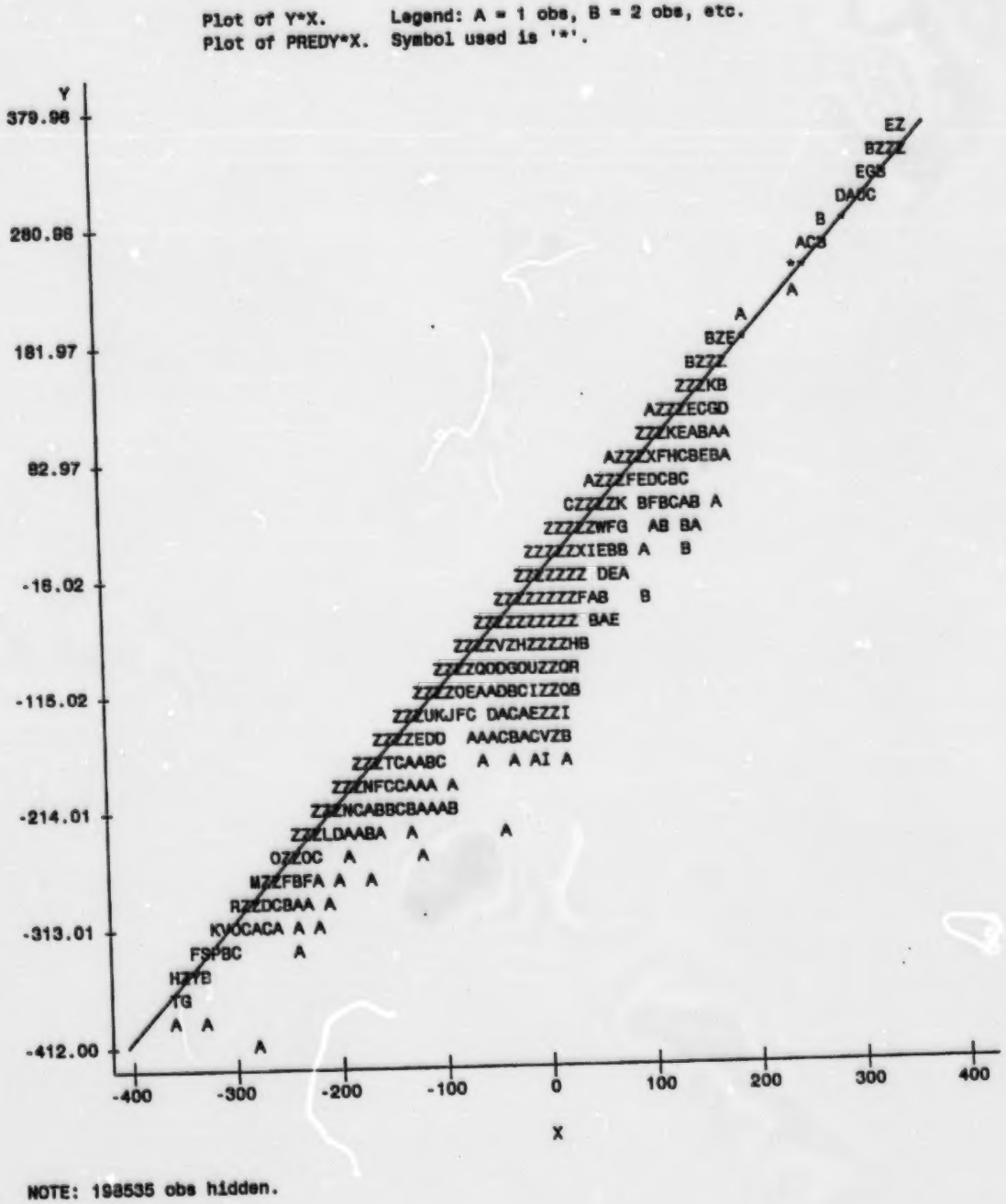


Figure 6: Regression of Y=RDD-Date Received over X=RDD-Date Shipped

The regression (a straight line) is represented on Figure 6. It means that if the time left to the RDD for a given consignment was 16 days at the time of shipment, then the expectation is that the time left to the RDD when the consignment is received would be -9 + 16 = 7 days. The R^2 for this regression was 0.89. R^2 measures how much variation in the dependent variable Y can be accounted for by the model. R^2 is inferior or equal to one. The larger the value of R^2, the better the model's representation. Other parameters such as the transportation mode, the materiel priority code, and whether a consignment is a dangerous good or not, were considered in the model. Even though these other parameters were found to be statistically significant, their influence on the R^2 value was negligible. For the sake of simplicity these parameters were not included in the regression. Note that even though the regression is a reasonable fit, the points are not spread so evenly around the line. The 9 days difference between X and Y could be compared with the transportation days calculated per materiel priority codes in paragraph 12. The medians varied between 3 and 7 days. The regression is influenced by large values in the data which explains the difference.

IV. CARRIERS PERFORMANCE

16. The performance of commercial carriers can be measured by the cost per weight and distance and the timeliness of the shipments. Timeliness because this is the basic requirement to be effective. Cost per weight and distance because it allows us to compare carriers' prices over different types of shipments (whether large or small, over short or long distances), even over different modes of transportation (the distance considered being the shortest distance between the origin and the destination). These comparisons between commercial carriers can be helpful to the TAs in making more judicious decisions when time comes to decide on how best to deliver a given consignment.

17. A sample of all shipments transported by commercial carriers from July 1 1996 to February 11 1997 was retrieved from the NMDS and analysed. Very few of those shipments had

actually been priced (Figure 7). The best proportion of such an occurrence was with Courier where 43% of shipments were priced. Moreover, commercial carriers' shipments were given BMSE, IBBS, SAIR, SRFS as modes of transportation when these modes are using strictly DND equipment. A better understanding of the selection of codes for the modes of transportation by the user is needed, together with a validation of the entries.

18. A comparison between commercial carriers in the field of commercial air, courier, post and road was made. Rail, Water and the "Other" modes were not analysed further since the number of recorded shipments that contained price information were too low. A total of 27 carriers were looked at, each having at least 30 observations under one transportation mode for a total of 11 133 shipments. The percentage of damage done to shipments was not used as a criteria of comparison between carriers: only one shipment amongst the 11 133 suffered damage. Similarly shipments with dangerous goods were not analysed separately: they represented only 2.6% of the 11 133 shipments.

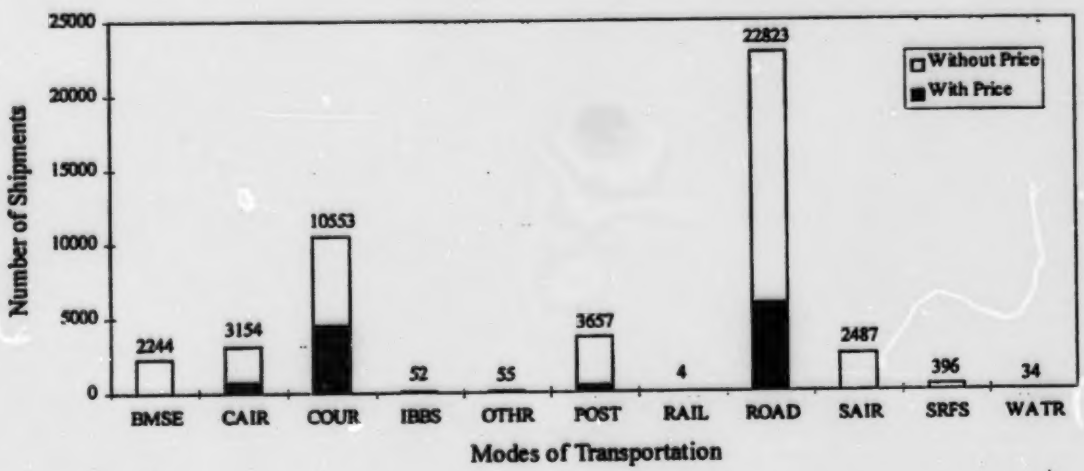


Figure 7: Distribution of Shipments by Transportation Mode

19. The cost performance of a commercial carrier for a given shipment was calculated as follows:

$$\frac{\text{cost of shipment}}{\text{weight of shipment x shortest distance between origin and destination}}$$

where the cost was expressed in cents (¢), the weight in kilograms (kg), and the distance was in kilometers (km). The distance used in the measure is not necessarily the distance covered: it is the shortest distance between the origin and the destination (see Annex A). Its advantage is that it allows comparison of the cost performance of two carriers regardless of the mode of transportation they used, be it commercial air or road.

20. The cost performance of a commercial carrier is then the average of this measure over a number of shipments along with its confidence interval (the average can be taken over all shipments, over all shipments within one mode of transportation, depending on what is being compared).

21. The timeliness was determined by comparing the numeric character of the transportation priority code (TPC) with the difference between the date received and the date shipped for a given shipment. Note, however, that the TPC gives lower and upper boundaries (Table II) for the time to the RDD from the time the materiel is presented to the shipper not from the date the materiel is shipped. But since there was no other information on the timing to the shipment, this was a best estimate.

22. Time performance for a given shipment is determined as follows. If the transportation time (date received - date shipped) is below the lower boundary then we are too early by a (positive) number of days. Often there is no advantage in delivering items earlier than the assigned due date. It might actually create problems when items need to be stored for a prolonged period of time. If the transportation time is within the lower and upper boundaries then we are on target and a zero value is assigned. If the transportation

time is beyond the upper boundary then we are too late by a (negative) number of days. Such a delay could be crucial in whether or not a mission is accomplished.

23. The timeliness of a commercial carrier is then evaluated by the average of the time performance over a number of shipments along with its confidence interval. Cost and time averages along with their 95% confidence intervals were determined for four modes of transportation: Commercial Air, Postal, Courier, and Road. The results are illustrated on Figures 8 to 11 and the averages are presented in Table V, while the full name of the commercial carriers can be found in Annex B. It is important to note that the values obtained are a reflection of the use made of the carriers in the last six months of 1996 and that the averages are taken over various types of shipments. It would be interesting to compare alternative commercial carriers, prior to shipment, using the cost performance measure. Timeliness has to be based on past experiences.

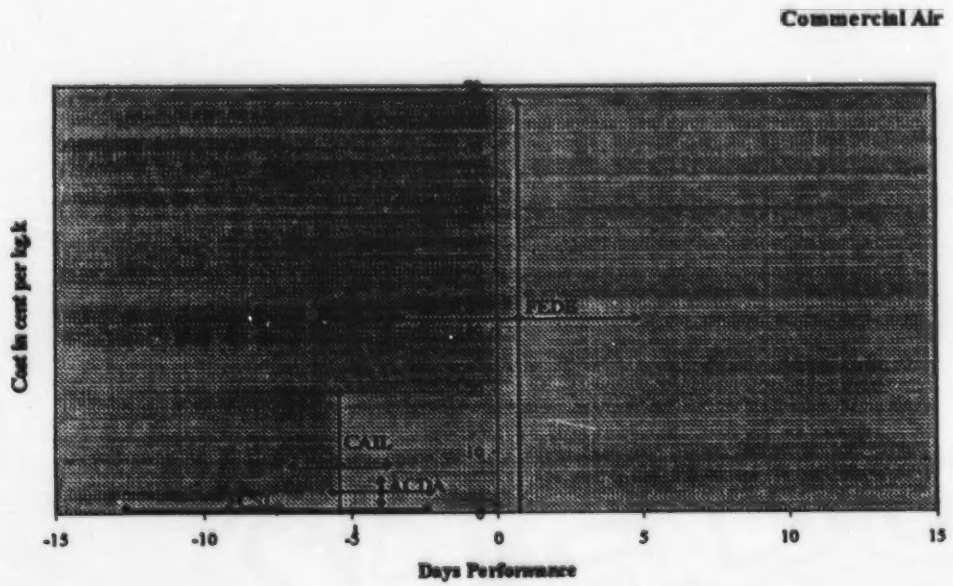


Figure 8: Performance of Carriers in Commercial Air transport

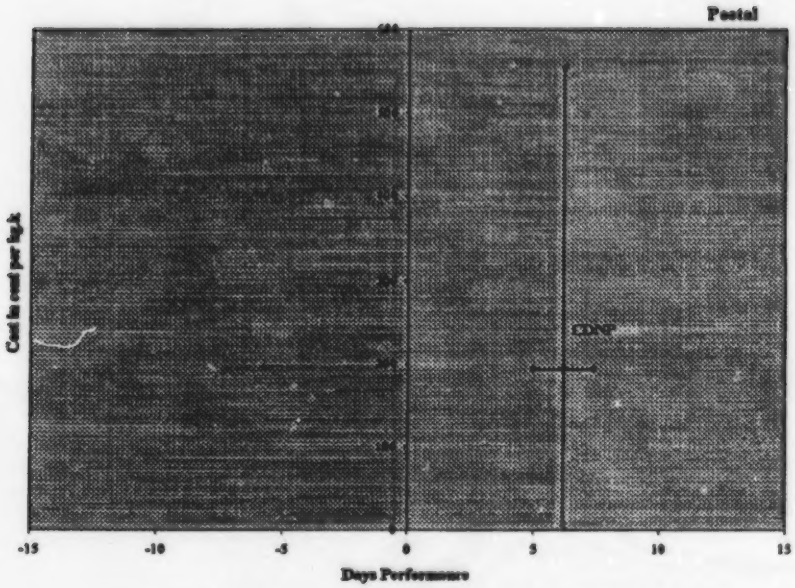
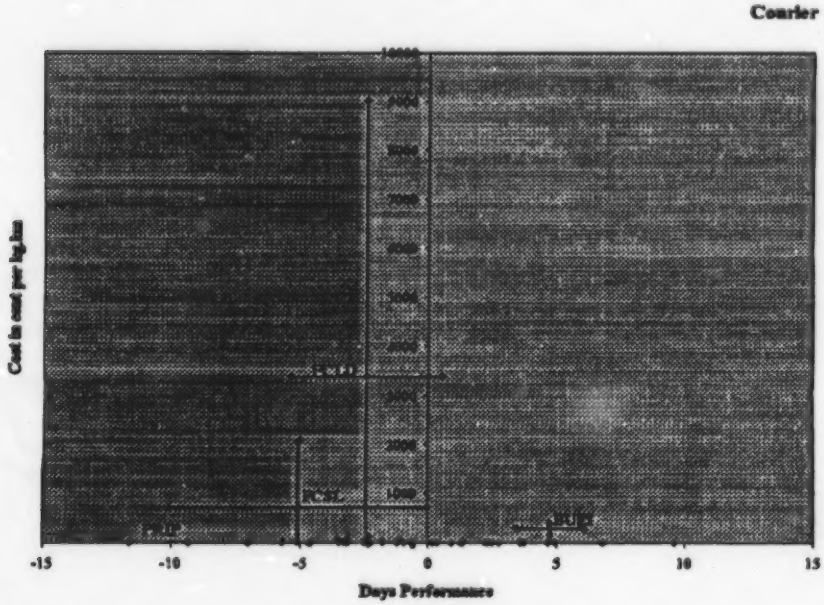
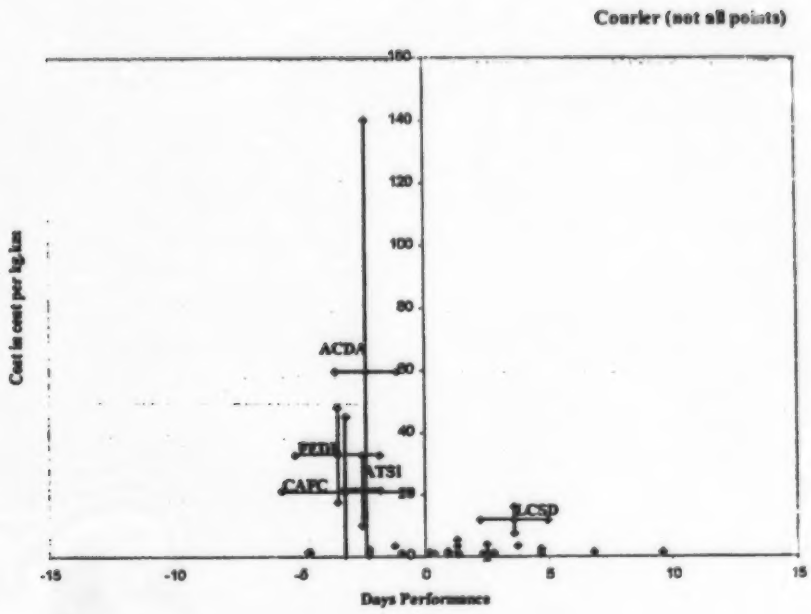


Figure 9: Performance of Carriers in Postal Services



(a)

Figure 10: Performance of Carriers in Courier Services



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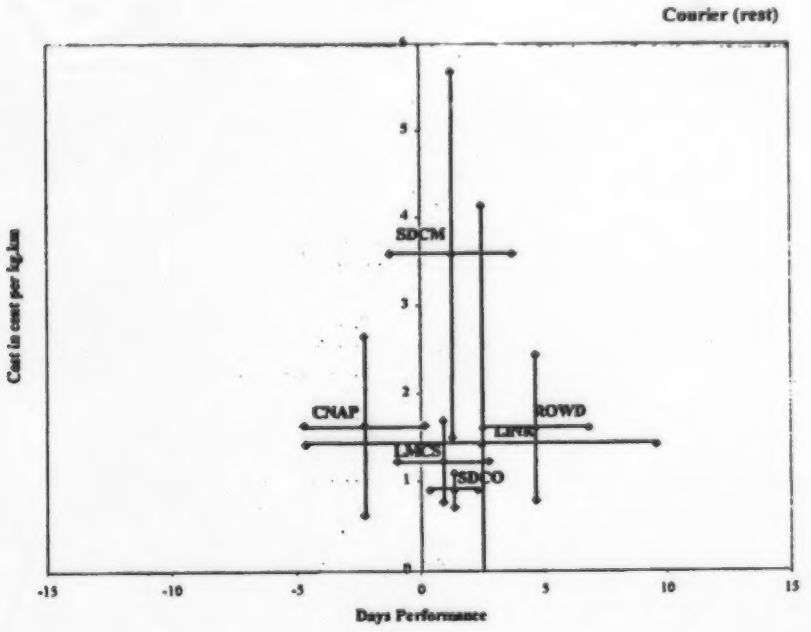
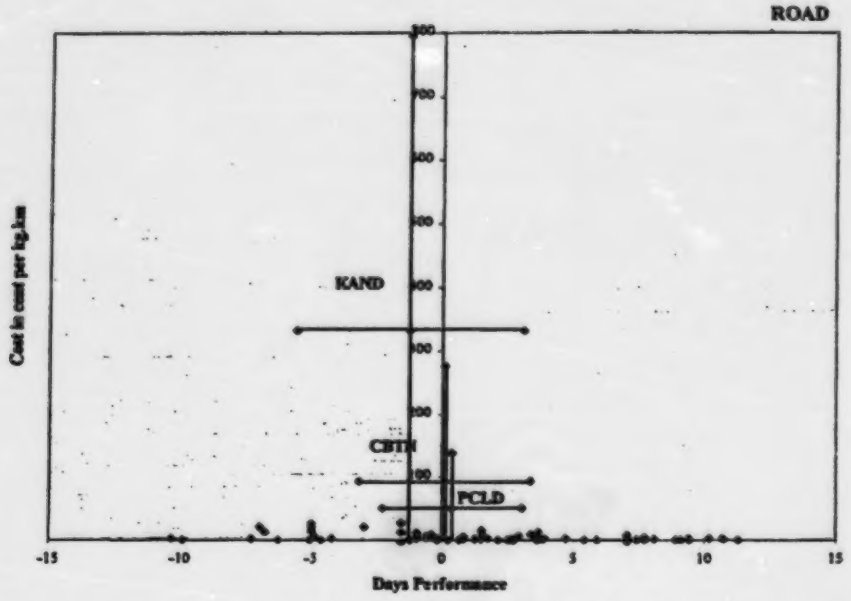
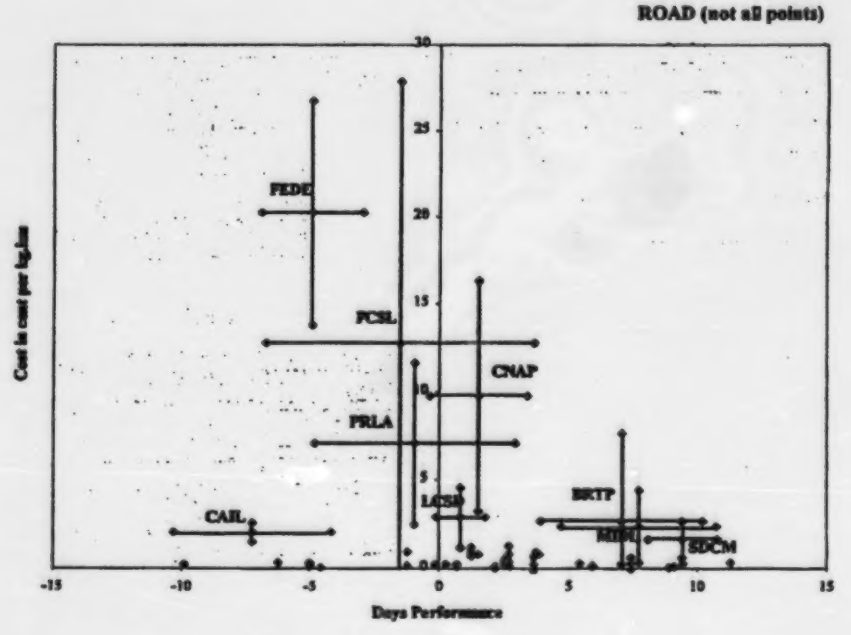


(c)

Figure 10: Performance of Carriers in Courier Services (continued)

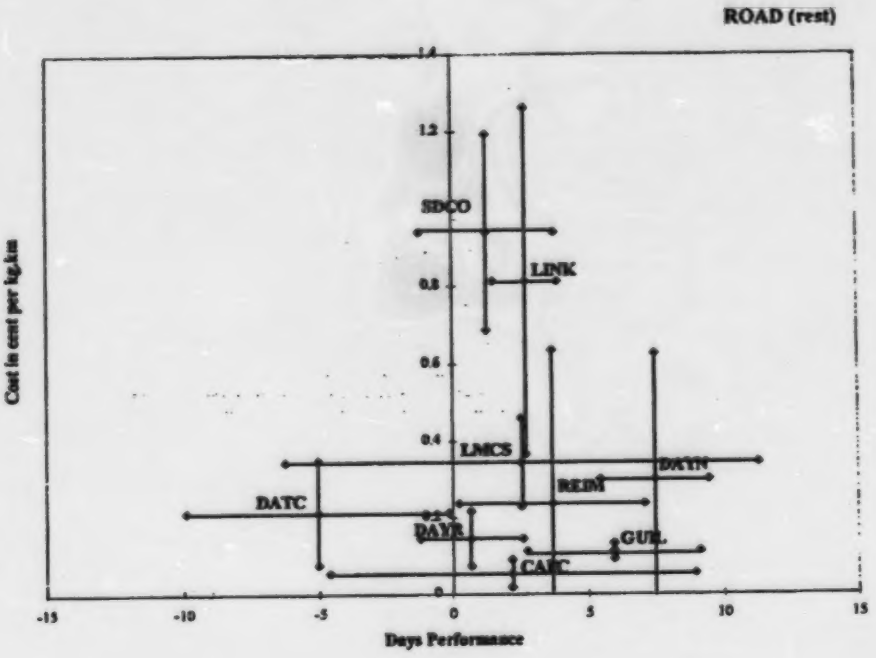


(a)



(b)

Figure 11: Performance of Carriers in Road Transport



(c)

Figure 11: Performance of Carriers in Road Transport (continued)

24. When looking at Figures 8 to 11, the carriers whose cost per weight and distance is lower and whose timeliness' measure is closest to zero are better. In some instances it appears that both criteria are difficult to meet together as in Figure 8. FEDE is better from the point of view of timeliness but it is expensive. ACDA is not very costly but tends to be late in meeting the due date. Also, between carriers whose crosses are large and those whose crosses are small, the smaller ones are better: it implies, on the basis of the observations, that these carriers provide the same quality of service more consistently than the others. While the cost measure is clearly a reflection of the performance of the carrier, the timeliness as measured here is not. To measure the time performance of the carrier per se we should be comparing the time the carrier was to pick-up the shipment with the

TABLE V

AVERAGE PERFORMANCE OF COMMERCIAL CARRIERS

Mode	Carrier	Time	Cost
CAIR	ACDA	-3.99	3.48
	CAIL	-5.41	7.82
	FCSL	-7.54	0.85
	FEDE	0.73	31.79
COUR	ACDA	-2.34	59.77
	ATSI	-2.52	21.53
	BUEI	4.73	280.69
	CAFC	-3.16	21.23
	CNAP	-2.25	1.64
	FCSL	-5.08	725.96
	FEDE	-3.49	32.91
	LCSD	3.58	11.94
	LINK	2.49	1.42
	LMCS	0.90	1.23
	PCLD	-2.46	3392.18
	PRIP	-9.32	3.50
	ROWD	4.66	1.61
	SDCM	1.26	3.59
	SDCO	1.33	0.91
POST	CDNP	6.16	193.93
ROAD	BRTP	7.05	2.66
	CAFC	2.17	0.05
	CAIL	-7.26	2.04
	CBTN	0.12	93.97
	CNAP	1.52	9.76
	DATC	-5.02	0.21
	DAYN	7.43	0.30
	DAYR	0.69	0.15
	FCSL	-1.53	12.76
	FEDE	-4.94	20.24
	GUIL	5.92	0.11
	KAND	-1.23	333.24
	LCSD	0.83	2.89
	LINK	2.69	0.81
	LMCS	2.53	0.35
	MIDL	7.71	2.40
	PCLD	0.39	50.29
	PRLA	-0.95	7.06
	REIM	3.65	0.24
	SDCM	9.41	1.64
	SDCO	1.26	0.94

actual time the shipment was picked-up. Similarly, the time the carrier was to deliver the shipment should be compared with the time the shipment was actually delivered. Currently the time performance reflects on how well the carrier meets the requirement set in the Transportation Priority Code while the carrier's responsibility lies in meeting its pick-up and delivery times.

25. The best "performances" by commercial carriers are as follows depending on the mode of transportation. For commercial air transport, ACDA is better if timeliness is not crucial. Otherwise FEDE should be used. It is, however, the most expensive carrier of the group. For courier services, SDCO and LMCS have both timeliness and cost performance. Canada Post Corporation or CDNP is in the postal services on its own. However, since the services that it performs for DND are comparable to Courier Services, there is no reason to exclude it from that group. Canada Post Corporation is found to be more expensive than the best courier carriers. Under road transport, DAYR and SDCO are the best carriers. Unfortunately, some carriers provide services only in some regions and are not real options to all TAs.

V. EFFICIENCY OF CMTTS

26. The efficiency of the CMTTs was measured by the ratio of the quantity of materiel handled by the CMTT over the number of individuals in the CMTT: the quantity of materiel handled representing what is concretely accomplished by the CMTT while the number of individuals in the CMTT represents the resources used (directly or indirectly) to accomplish this. Of course it is understood that the CMTT personnel may have other tasks (not accounted for here), but the most important is the distribution of materiel. The idea here is to determine the best performing CMTTs to be used as benchmarks for the others.

27. For personnel figures, we relied on numbers collated by DTM as of 19 April 1996. The numbers used represent the total number of individuals working at each base CMTT at the time. To measure the quantity of materiel handled by a CMTT two parameters were available: the number of consignments (received and staying at the CMTT and those leaving the CMTT, i.e., issues and reroutes) and the weight of that materiel. Both were determined for each CMTT for the period of 1 March to 31 May 1996. The data gathered is presented under Table VI.

TABLE VI

DATA ON BASE CMTTS

CMTT	Number of people	Total number of consignments	Total weight (Kg)
Base1	4	1 410	150 344.37
Base2	12	2 571	2 039 778.67
Base3	5	2 032	566 151.61
Base4	5	1 316	591 279.67
Base5	8	2 812	655 036.29
Base6	4	2 288	442 033.38
Base7	8	2 796	667 684.47
Base8	4	510	88 710.78
Base9	1	743	85 785.49
Base10	7	947	719 359.82
Base11	1	1 015	299 750.60
Base12	13	3 788	1 200 419.95
Base13	6	1 974	726 203.56
Base14	3	730	231 644.18
Base15	8	2 740	4 055 361.73
Base16	5	1 427	149 884.09
Base17	6	2 175	5 873 639.66
Base18	8	2 952	5 786 174.95
Base19	15	4 025	854 769.70
Base20	5	1 887	189 308.77
Base21	3	759	22 230.39
Base22	6	2 547	271 004.28
Base23	3	632	47 239.38
Base24	4	573	203 279.50
Base25	12	2 437	439 414.46

28. To compare the CMTTs to one another we can use the number of consignments handled per person or the weight handled per person as illustrated in Figures 12 and 13. However each one is not sufficient in itself. When the number of consignments is used as a criteria, Base11 shows as the best CMTT. If all consignments had the same weight and size, that would be essentially the only criteria needed. However, consignments do vary in size and weight. And size and weight have an influence on the quantity of consignments that can be handled. When CMTTs are compared based on weight, Base17 rates as best. As implied here the volume would have been a desirable parameter to use, however since it is often missing from NMDS records, it was not used in this analysis. A more complete analysis of the CMTTs should apply over a longer period of time and include volume and a measure of the timeliness in the handling of the materiel.

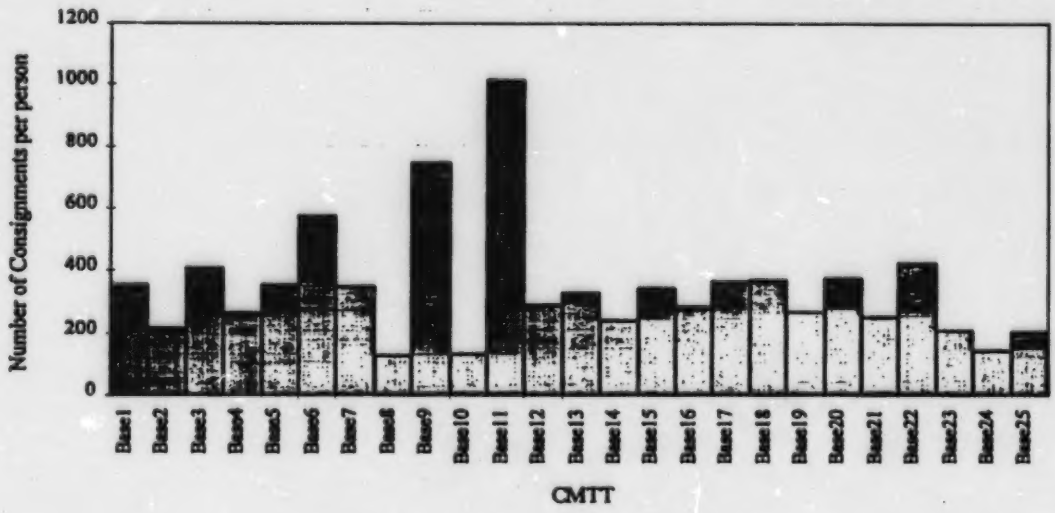


Figure 12: Consignments handled by CMTTs

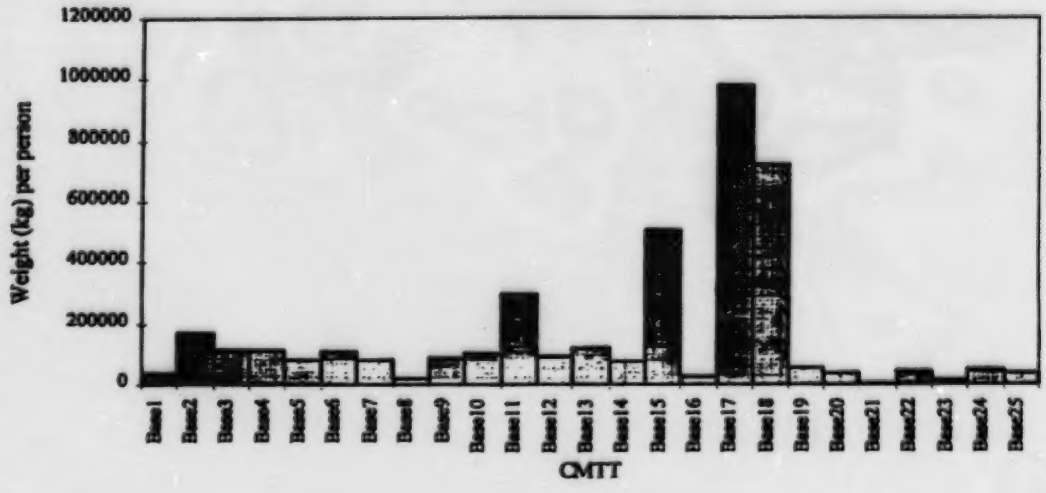


Figure 13: Weight handled by CMTTs

29. A Data Envelopment Analysis (DEA) was used to rate CMTTs relative to one another. The method gives a rating that is non-negative and gives a value of 1 to the best performing CMTTs. It is important to note here that these measures are all relative. Thus if all CMTTs are good, even the worse performing one is good. Similarly, if all CMTTs are functioning poorly, the best performing one is the best amongst the "bad" so to speak. The DEA model used here is presented in Annex C. The results are shown in Figure 14. Base11 and Base17 have ratings of 1, followed by Base18 (0.82), Base9 (0.73), Base15 (0.64), etc. What is also interesting from this analysis is that since Base11's CMTT has only one individual, it provides an idea of what could be expected per person. Base11 handled about 1 015 consignments / 3 months ≈ 338 consignments per month for a total weight of 299 750.60 kg / 3 months ≈ 100 000 kg per month.

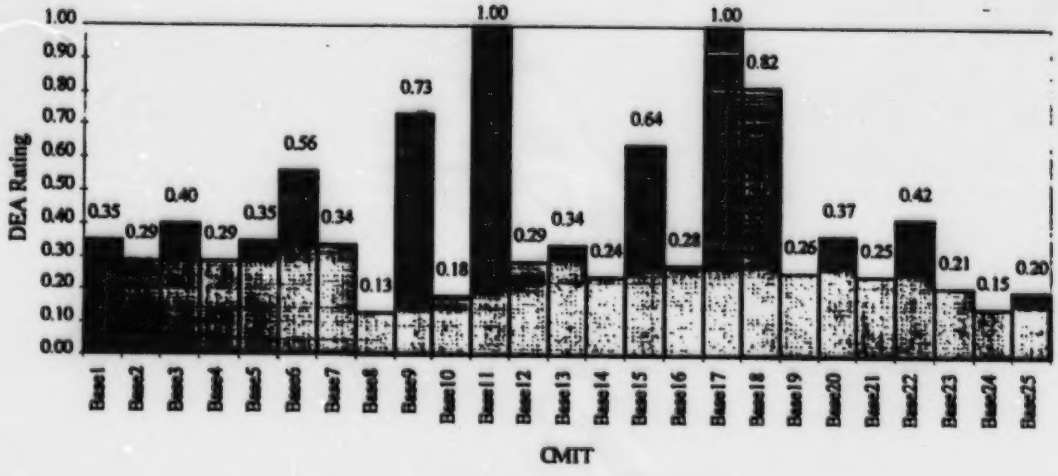


Figure 14: DEA Rating by CMTTs

VI. RECOMMENDATIONS

30. Two aspects need to be addressed in order to improve our measures of the materiel distribution within DND. One is the quality of the information. There is a need to validate the data entries in the NMDS such as the date of reception, the Required Delivery Date, the mode of transportation. In the latter case, there is a need to educate the user as to the meaning of each code for the modes of transportation since commercial carriers were given BMSE, IBBS, SAIR, SRFS i.e. modes of transportation which are using DND resources only. CDNP, the Canada Post Corporation, was occasionally given ROAD instead of POST as the mode of transportation. The price of a shipment, the volume of a consignment were not often present in the NMDS.

31. Besides improving the quality of the information, there is a need to add to it. On timing, besides the date of shipment, the date of reception, and the RDD, there is a need for the demand date, the date to movement and, for commercial carriers there is a need for the agreed and actual pick-up date and delivery date in order to identify where delays occur. The commercial carriers timing could then be measured according to their commitments. It would also be interesting to know, when using departmental resources, which vehicle was used, that is, link the NMDS to the fleet management database. An equivalent price could then be associated to a shipment carried through our own resources and compared to that of commercial carriers.

VII. CONCLUSION

32. The materiel distribution system was looked at from the point of view of performance. Evaluations were made through usage of the NMDS. The data showed that the percentages of consignments meeting their required delivery dates were generally low. They were all below 50% for materiel priority codes 0X, 01, and 02, i.e., the high priorities. The accuracy of the dates, particularly the reception dates and RDDs was questioned. Commercial carriers were compared to one another using a cost measure and a timeliness measure. Some of them were identified as best performers under a mode of transportation. The modes considered were: commercial air, postal, courier, and road. It was felt that additional information such as the actual and intended times of pick-up and the actual and intended times of delivery would be needed to truly evaluate the carrier's time performance. Lastly, the efficiency of base CMTTs was looked at in terms of total number of individuals per CMTT and the materiel they each handle. The CMTTs were all rated to one another: two bases were shown to be the best performing CMTTs in that they could do more with the resources they had, this, considering strictly the number of individuals and the materiel handled.

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SHORTEST DISTANCE BETWEEN THE ORIGIN AND THE DESTINATION

1. Using the latitude and longitude of the origin and that of the destination expressed in spherical coordinates (as illustrated in Figure A-1), we deduce the shortest distance between them.

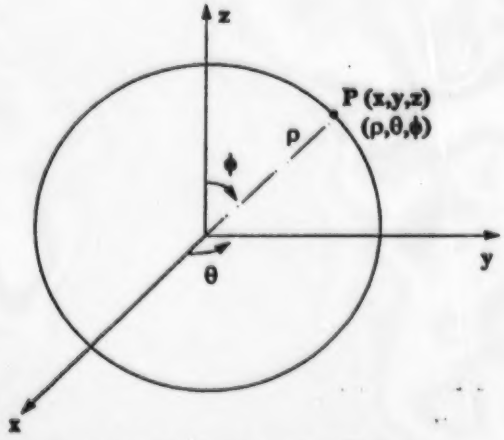

Figure A-1: Spherical Coordinates

2. Let a, b, c represent the sides of any spherical triangle (Figure A-2) where each side is measured by the angle subtended at the centre of the sphere, and A, B, C the corresponding angles. Then we can deduce "$\rho_0 a$", the distance between the origin and the destination, knowing A, b, and c [5]:

$$\cos a = \cos b \cos c + \sin b \sin c \cos A$$

$$\cos a = \cos \phi_1 \cos \phi_2 + \sin \phi_1 \sin \phi_2 \cos |\theta_1 - \theta_2|$$

$$\rho_0 a = \rho_0 \arccos \{\cos \phi_1 \cos \phi_2 + \sin \phi_1 \sin \phi_2 \cos |\theta_1 - \theta_2| \}.$$

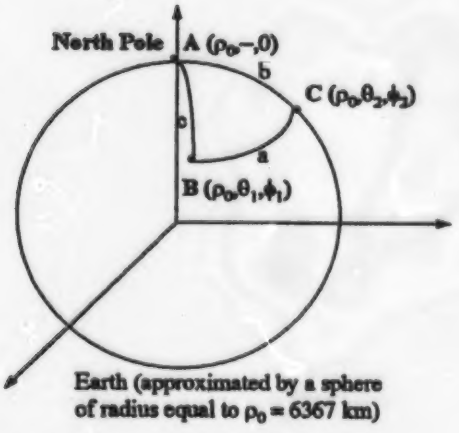

Figure A-2: Spherical Triangle

COMMERCIAL CARRIERS NAMES

Carrier Code	Carrier Name
ACDA	Air Canada (Winnipeg)
ATSI	Andlauer Transportation Services - BC
BRTP	B and R Eckels Transport Ltd - Bonnyville
BUEI	Burlington Air Express (Toronto)
CAFC	Cottrell Air Freight Ltd
CAIL	Canadian Airlines Intl (Vancouver)
CBTN	Cabano Transport Ltd (Ancienne-Lorette)
CDNP	Canada Post Corporation (Ottawa)
CNAP	CANPAR (Mississauga)
DATC	Daily Transport
DAYN	Day and Ross (NFLD) Ltd (Grand Falls)
DAYR	Day and Ross Ltd (Moncton)
FCSL	Fastair Cargo System Ltd
FEDE	Federal Express (Mississauga)
GUIL	Guilbault Transport - Montréal NO LONGER USED
KAND	Kando Transport Ltd (Etobicoke)
LCSD	Loomis Courier Services
LINK	Interlink Freight Services
LMCS	LOOMIS COURIER SERVICE
MIDL	Midland Transport Ltd
PCLD	Purolator Courier Ltd
PRIP	Priority Post Courier
PRLA	PUROLATOR
REIM	Reimer Express Lines Ltd (Winnipeg)
ROWD	Right-O-Way Air Express & Cargo
SDCM	Sameday Courier
SDCO	Same Day Right O Way Courier

ANNEX C
ORD PR-9718
DECEMBER 1997

DEA MODEL FOR CMTTS

1. In the basic DEA methodology, a number of decision making units (DMUs) are compared. In this specific analysis, DMUs are CMTTs. Each of which uses various amounts of a number of distinct inputs to produce various levels of a number of distinct outputs. The CMTTs are indexed by $j = 1, 2, ..., 25$ since there are twenty-five base CMTTs being compared, the inputs accounted for are simply the number of individuals (indexed by $i = 1$), and the outputs are indexed by $r = 1, 2$ respectively for the number of consignments handled, and the weight in kg of materiel handled. X_{ij} is the amount of input i used by CMTT j and Y_{rj} is the amount of output r produced by CMTT j. DEA seeks to get the best productivity score for each CMTT. DEA seeks optimal solutions to the 25 fractional programs ($k = 1, 2, ..., 25$):

$$Max\ P_k = \frac{\sum_r u_{rk}\ Y_{rk}}{\sum_i v_{ik}\ X_{ik}}$$

subject to

$$\frac{\sum_r u_{rk}\ Y_{rj}}{\sum_i v_{ik}\ X_{ij}} \leq 1 \qquad \forall j$$

$$u_{rk} \geq 0 \quad \forall r$$

$$v_{ik} \geq 0 \quad \forall i$$

2. That is for each CMTT, its productivity is determined by a weighted sum of outputs over a weighted sum of inputs. The weights being chosen such that they are non-negative, and the productivity of all CMTTs with these weights do not exceed 1. It is understood that all *X*s and *Y*s are non-negative and that for given amounts of input (Xs), the amounts of output (Ys) augment with productivity.

3. Thus for each CMTT, weights are chosen so that this CMTT gets its best productivity value. That being done for all CMTTs, the results are productivity scores that represent each one favorably. Each CMTT score obtained is the highest score that could be attributed to this CMTT from comparison to the other CMTTs. What this means is that when the score is low the CMTT is really doing poorly compared to the others.

4. References [6] and [7] provide good discussions of the data envelopment analysis. The formulation presented above can be easily converted into the linear programs:

$$Max\ P_k = \sum_{r=1}^{2} u_{rk}\, Y_{rk}$$

subject to

$$\sum_{r=1}^{2} u_{rk} Y_{rj} - v_{1k} X_{1j} \leq 0 \quad j = 1,2,...,25$$

$$v_{1k} X_{1k} = 1$$

$$u_{rk} \geq 0 \quad r = 1,2$$

$$v_{1k} \geq 0$$

5. Ideally, we would want to impose that all weights be positive, to force the inclusion of all inputs and outputs in the determination of the productivity scores. However due to the large variation in the values of inputs and outputs, this may not be handled by all linear programming packages. By ensuring that the number of parameters used is less than or about half the number of DMUs considered, we avoid solutions that take advantage of the particularities of a DMU.

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Performance measures for the materiel traffic within the Canadian Forces were determined and evaluated. Three areas were addressed: the effectiveness of the distribution of Canadian Forces' materiel, the performance of commercial carriers, and that of the Central Materiel Traffic Terminals (CMTTs). The report shows that the percentages of consignments meeting their Required Delivery Date to be low for high priority consignments however the accuracy of several dates recorded is questioned. Commercial carriers were evaluated according to their cost per weight and distance and their timeliness. Finally the efficiencies of the CMTTs were compared to one another.

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materiel distribution
productivity
priority code
required delivery date
carrier